Applied Geography 93 (2018) 16–24

Contents lists available at ScienceDirect

Applied Geography

journal homepage: www.elsevier.com/locate/apgeog

An examination of the potential wetland development landscape around managed reservoirs in the central U.S. Great Plains

Kaitlyn M. Loeffler[a,c], Vahid Rahmani[b,c,*], Jude H. Kastens[c], Donald H. Huggins[c]

[a] Department of Civil, Environmental, and Architectural Engineering, University of Kansas, Lawrence, KS 66045, USA
[b] Department of Biological and Agricultural Engineering, Kansas State University, Manhattan, KS 66506, USA
[c] Kansas Biological Survey, University of Kansas, Lawrence, KS 66047, USA

ARTICLE INFO

Keywords:
Bathymetry
Lake level
LiDAR
Reservoir
Slope
Wetland

ABSTRACT

Reservoirs around the world are losing storage capacity due to sediment infilling, leading to reductions in the quality and value of reservoir uses. However, the sediment accumulating in the upper ends of reservoirs, particularly around primary inflows within well-defined floodplains, could potentially be developing into wetland ecosystems that provide services such as sediment filtration, nutrient sequestration, and wildlife habitat. In this study, we examine lake level, wetland, and topographic characteristics for 20 large, federally operated reservoirs in the state of Kansas located in the central U.S. Great Plains. First, daily water level data and empty-basin topography (created by merging LiDAR elevation with bathymetry) are used to delineate the primary fluctuation zone for each reservoir, which we define to be the range of extents between the 25th and 75th lake level percentiles. Next, we use data from the U.S. Fish and Wildlife Service National Wetlands Inventory (NWI) to characterize wetland composition in the upper fluctuation zone (extent range between the 50th and 75th lake level percentiles) and the upper flood pool (extent range between the 75th percentile and the maximum designed flood pool elevation). For the final assessment, we examine the relationship between ground slope and NWI in the upper fluctuation zone and the upper flood pool. Results indicate that relatively low-sloped ground is classified as wetland in the upper fluctuation zone at 24% greater frequency than in the upper flood pool.

1. Introduction

While man-made reservoirs and natural lake ecosystems are similar in their water usage, they differ in characteristics such as drainage area and age. Specifically, reservoirs are considerably younger than natural lakes and usually have larger drainage areas due to choice of location and purpose such as flood control (Cooke, Welch, Peterson, & Nichols, 2016; Hayes, Deemer, Corman, Razavi, & Strock, 2017). Soballe and Kimmel (1987) found that the ecological structure and function of rivers, river impoundments, and natural lakes on a broad scale varied along a composite gradient that changed with water residence time, drainage area, water depth, flow, and water clarity. Lakes and rivers occupied opposite ends of this spectrum with reservoirs typically occupying an intermediate position. Ecological structure maturity differences between natural lakes and reservoirs may reflect the artificial changes in water level and the disequilibrium state of reservoirs, given their anthropogenic origin, young age, and in some cases, regimented management.

It is generally understood that in natural lakes the spatial variation of many physio-chemical and biological factors are related to shoreline length, depth, and wind-driven currents (Thornton et al., 1981). By contrast, these attributes appear to be of less importance in reservoirs, where the prominent determinants of observed spatial gradients in physio-chemical and biological conditions are relatively large riverine inflows and depth gradients characteristic of damming the river channel to create an in-line impoundment (Lehner et al., 2011). These upstream-downstream gradients in depth and flow often result in measurable gradients in turbidity, mixing depths, nutrient concentrations, primary production, and fish standing stocks along with other characteristics (Kennedy, Gunkel, & Thornton, 1982; Kimmel & Groeger, 1984; Kimmel, Lind, & Paulson, 1990; Lind, 1984). The uppermost riverine zones of the reservoirs are characterized as shallow, light-limited and high nutrient zones, whereas the deeper, clearer water area near the dam functions more similarly to natural lakes (Kennedy, Thornton, & Ford, 1985).

As impoundments age, a common problem impacting reservoir management and sustainability is sediment infilling (deNoyelles and Kastens 2016; Rahmani et al., 2018; Schleiss, Franca, Juez, & De Cesare, 2016; Stene, 1946). This is particularly problematic in regions where precipitation, soil properties, topography, and land use all contribute to

* Corresponding author. Department of Biological and Agricultural Engineering, Kansas State University, 920 N. 17 Street, 1016 Seaton Hall, Manhattan, KS 66506, USA.
E-mail address: vrahmani@ksu.edu (V. Rahmani).

https://doi.org/10.1016/j.apgeog.2018.02.010
Received 12 August 2017; Received in revised form 31 January 2018; Accepted 13 February 2018
0143-6228/

high levels of soil erosion (García-Ruiz et al., 2015; Ziadat & Taimeh, 2013). One type of soil erosion specifically expected to be affected by climate change is gully erosion, in which increased and more frequent runoff events create favorable conditions for gully development (Nearing et al., 2004; Poesen, Nachtergaele, Verstraeten, & Valentin, 2003). Gully erosion from agricultural lands has been acknowledged as a major supplier of the total sediment loads flowing into reservoirs, indicating the importance of land use on sedimentation rates (Fox et al., 2016).

The disproportionately large amount of sediment brought in from cropland is especially important where farming communities make up a substantial portion of a reservoir's watershed. One such area is the state of Kansas located in the central United States, where cropland (approximately 50%) and grassland (approximately 42%) dominate the landscape (Peterson, Egbert, Price, & Martinko, 2004). With this land cover composition, and with its many large impoundments, Kansas is a good candidate for studying the impact of sedimentation on potential wetland formation around the upper ends of reservoirs (Rahmani et al., 2018). In addition to the inevitable aging and infilling process (deNoyelles and Kastens 2016), sediment infill rates may be increasing due to changes in the occurrence of extreme storm events (Coppus & Imeson, 2002; Mouri, Shiiba, Hori, & Oki, 2011; Valentin, Poesen, & Li, 2005). Kansas has seen an upward trend in the magnitude and frequency of extreme rainfall events during 1890–2013, with an even greater upward trend observed for 1981–2010 (Rahmani, Hutchinson, Harrington, & Hutchinson, 2016). With reduced water storage capacity and high sedimentation rates in the upper ends of many Kansas reservoirs, other impacts such as habitat loss (or gain) and water quality changes are being examined (Hargrove, 2008; Juracek, 2015).

One impact of sediment infilling is the increased area of shallow water and total amount of nutrient-rich sediments that go along with it (Cooke, Welch, & Peterson, 2013). It is well documented that the quality of water found in our water bodies has decreased due to the increased nutrients in agricultural runoff (Verhoeven, Arheimer, Yin, & Hefting, 2006). Shallow water and increased nutrient loads are two parameters often found in wetland ecosystems compared to natural water bodies. With land use change and climate change, particularly in areas also experiencing an increase in larger storms, reservoir hydrological and ecological characteristics may change more rapidly (Raje & Mujumdar, 2010; Singh, Sinha, & Sankarasubramanian, 2014; Soundharajan, Adeloye, & Remesan, 2016).

To help maintain the storage capacity of the reservoirs, the most immediate management plan is dredging, which is significantly costly. For example, $20 million (U.S.) was expended to remove 2.3 million cubic meters of sediment from John Redmond Reservoir in Kansas in 2016, which added approximately three more years of life for the reservoir (KWO, 2015; Rahmani et al., 2018). The cost of disposing dredged sediment can also be high, especially if the sediment contains harmful chemicals or trace metals such as arsenic, copper, lead, or mercury (Hargrove, Johnson, Snethen, & Middendorf, 2010). A possible alternative management strategy for these reservoirs whose upper end riverine zones are becoming shallower could be to manage these areas as wetlands if wetland characteristics exist. By filtering inflow through wetlands, in addition to improving water quality, this approach could slow the transmission of sediment into the main body of the reservoir where the storage capacity typically is most needed.

According to the map coverage in Schenck, Wedel, and Monda (1992), most wetlands on cropland occur in the eastern one-third of Kansas. Additionally, most wetland types listed for Kansas primarily occur in far eastern Kansas, and the south-central and west-central portions of the state. It has been estimated that almost half of the historic wetlands in Kansas have been lost through drainage and agricultural land conversion (KGS, 2017). While it is unclear exactly where all of these wetlands were lost to agriculture, it is reasonable to assume that many were located in riparian and floodplain areas of the east where much of the land is farmed and many remaining wetlands persist.

This project aims to examine potential wetland development areas along the perimeters of federal reservoirs in Kansas to facilitate conservation and management of these potential resources for their ecological goods and services to society. The United States Army Corp of Engineers (USACE) offers legal protection to natural wetlands under Section 404 of the Clean Water Act if the wetland has hydrological characteristics, hydrophytes, and hydric soils (Johnson, 1992).

The objectives of this study are to 1) use water level management data and topography to delineate the primary zone of potential wetland formation around the reservoir perimeter, 2) use data from the U.S. Fish and Wildlife Service National Wetlands Inventory (NWI) (USFWS, 2016) to characterize wetland composition in the reservoir flood pool, and 3) examine the relationship between ground slope and NWI occurrence in the reservoir flood pool. We use the NWI because it is currently the only documented source of delineated wetlands in Kansas and is a widely used and well-known standard despite uncertainties regarding its accuracy and completeness.

2. Methods and materials

2.1. Study area

The study sites consist of the 20 federally operated reservoirs in the state of Kansas that had both LiDAR elevation data (to represent topography outside the reservoir) and bathymetry data (to represent lake-bottom topography inside the reservoir) at the time of the analysis (Fig. 1; there are 24 federal reservoirs in Kansas, leaving four that did not satisfy these criteria). Reservoir watersheds for these 20 reservoirs consist mostly of grassland (58% of watershed area) and cropland (37%) (Martinko et al., 2014). General physical characteristics of this set of reservoirs are provided in Table 1.

Two distinct climates cover Kansas, ranging gradually from a humid climate in the east to a semi-arid climate in the west. Average precipitation rates vary from approximately 1150 mm in the southeastern portion of the state to approximately 500 mm in the far west. The average temperature patterns go from the warmest in the southeast to the coldest in the northwest, with a statewide average low of 0 °C in January and an average high of 27 °C in July. All of the study reservoirs are located in the central and eastern part of the state, where precipitation ranges from approximately 600–1000 mm annually; however, the watersheds for the central reservoirs extend into the western portion of Kansas where there is less precipitation annually (Goodin, Mitchell, Knapp, & Bivens, 1995; Rahmani, Hutchinson, Harrington, Hutchinson, & Anandhi, 2015).

2.2. Hydrological analysis

Historic water level elevation data and reservoir basin topography (a blend of LiDAR digital elevation data and bathymetry information) were used to determine the zone around each reservoir that captures the range of extents between typical dry conditions (25th percentile water level) and typical wet conditions (75th percentile water level), which we term the *fluctuation zone*. Within the *upper fluctuation zone* (the region between the 50th and 75th percentiles) and the *upper flood pool* (the region between the 75th percentile and the designed maximum flood pool level) we then examined median ground slope values summarized across wetland delineations from the NWI dataset. The historical reservoir water level data provided the range of typical water level elevations during wet and dry periods. These data were requested or retrieved from the USACE (USACE 2016a; USACE 2016b), the U.S. Geological Survey (USGS) (USGS 2016), and the U.S. Bureau of Reclamation (USBR 2016). For nine of the reservoirs, data were used starting the day that the reservoir first reached its regulation level through 2015. For ten of the reservoirs, data were used from the beginning of digital record keeping in 1995 through 2014 or 2015. For